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Executive Summary Report

THE APPLICATION OF AIRBORNE IMAGING RADARS (L- AND X-BAND) TO EARTH RESOURCES PROBLEMS

June 1, 1973 Through April 30, 1974

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16. Abstract

The Environmental Research Institute of Michigan (ERIM) has recently developed a multiplexed synthetic aperture Side-Looking Airborne Radar (SLAR) that simultaneously images the terrain with X-band (3.2 cm) and L-band (23.0 cm) radar wavelengths. In Brevard County, Florida, ERIM has begun an experimental program directed toward determining the feasibility of using multiplexed SLAR to obtain useful information for the following earth resources purposes: (1) Direct or indirect detection of pools of water under standing vegetation, and specifically under canopies of dense vegetation. (2) Urban and rural land-use planning. (3) Water resources management. (4) Determination of drainage patterns.

In early October, 1973, three test areas in Brevard County were imaged with the multiplexed SLAR. Concurrent with the radar imaging, ground truthing of selected places and features within the test areas was conducted to: (1) Document conditions in the test areas for each of the four earth resources purposes during the radar data gathering. (2) Ground truth any places or features which had unexpected or interesting returns on the radar imagery. (3) Make field measurements of the complex dielectric constant of vegetation using portable microwave equipment.

In late October, 1:24,000 scale black and white aerial photography and 8 - 12.5 micron thermal infrared (IR) imagery of the three test areas was gathered. The thermal IR imagery was gathered within two hours after sunrise.

(Continued)

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FOREWORD

For convenience in referring to more detailed information, the sections in this Executive Summary Report correspond to the sections in the Detailed Technical Report.

The research described in this final report was performed by the Environmental Research Institute of Michigan (ERIM). The work was supported by the John F. Kennedy Space Center, NASA. The inclusive dates for this reporting period are June 1, 1973 through April 30, 1974. The Kennedy Space Center Technical Manager for this experiment was Edward J. Hecker. The Co-Principal Investigators were Robert A. Rendleman and Ben Drake. ERIM's number for this report is 104000-1-F.

Many scientists and technicians from ERIM have contributed to this experiment. The authors are especially indebted to the ERIM technicians who gathered and processed the radar imagery. John Hutton and Frank Brake from the Brevard Mosquito Control District helped with the ground truthing, as did Joe Brooks from Melbourne Beach, Florida. Their help is gratefully acknowledged.

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THE APPLICATION OF AIRBORNE IMAGING RADARS (L- AND X-BAND) TO EARTH RESOURCES PROBLEMS

1
PURPOSE OF THE EXPERIMENT

The Environmental Research Institute of Michigan (ERIM) conducted an experimental program utilizing its multiplexed synthetic-aperture X- and L-band Side-Looking Airborne Radar (SLAR) for the following specific earth resources purposes:

A. Detection of pools of water under standing vegetation. The pools could be detected either directly or indirectly.

B. Land-use planning. For the purposes of this report, land use is loosely divided into urban, rural, and environmental. Areas of urban land use are areas of intensive use where much of the land is covered by structures. Rural land use is concerned with non-urban areas. Environmental land use is concerned with specific environmental problems — such as a species habitat.

C. Water resources management. Mapping water bodies and the vegetation in them.

D. Determination of drainage patterns.

2
BACKGROUND

Extensive work is being done to investigate ways in which photographic, multispectral scanning, and thermal infrared imagery may be applied to the solution of earth resources problems. The various remote sensors have imaging capabilities that complement and supplement each other in terms of the data that can be gathered concerning a specific earth resources problem or feature.

ERIM has recently developed a multiplexed synthetic aperture SLAR that simultaneously images the terrain with X-band (3.2 cm) and L-band (23.0 cm) radar wavelengths. Both like- and cross-polarized energy is reflected back to the transmitting antenna for each wavelength, thus four channels of radar imagery are simultaneously recorded.

Previously, with a SLAR capable of transmitting only a single-wavelength at any one time, it was necessary to image a region on successive passes when multiple wavelength imagery was desired. This constraint causes problems not only in image gathering but also in interpretation, particularly if a significant length of time intervenes between the imaging passes. In comparison, multiplexed SLAR imagery has several inherent advantages: for all the multiplexed wavelengths there are identical imaging parameters (radar look direction, depression angles, etc.), the same imaged swath, the same motion errors, and the same terrain conditions (surface texture, slope orientations, vegetation, etc.).

Previous radar imagery gathered by ERIM had demonstrated the usefulness of SLAR for determining drainage patterns, for water resources management and, to an unknown extent, for land-use planning. However, the usefulness of remote sensing techniques, especially SLAR, in detecting pools of water under standing vegetation and particularly under canopies of dense vegetation had not been thoroughly explored.

3
PROPOSED TEST AREAS AND SITES

Five test areas in Brevard County, Florida were selected to be imaged by the multiplexed SLAR. Within these test areas, only a few specific test sites were chosen—particularly cities of Titusville and Melbourne, and certain areas with pools of water under dense canopies of vegetation. Table 1 enumerates the test areas, their locations, and the specific earth resources problem(s) for which they were selected. Only Test Areas 1, 2, and 3 were imaged during the experiment.

TABLE 1. DESCRIPTION OF PROPOSED TEST AREAS IN BREVARD COUNTY, FLORIDA

Test Area	Location	Earth Resources Problem(s)
1	Western side of Merritt Island	Primarily detection of pools of water under standing vegetation. Secondarily, rural land use and water resources management.
2	Western shore of the Indian River	Primarily urban land use (particularly the cities of Titusville and Melbourne) and rural land use. Secondarily, water resources management and detection of pools of water under standing vegetation.
3	Upper part of the St. Johns River	Primarily water resources management and determination of drainage patterns. Secondarily, rural land use.
4	Canaveral Peninsula	Environmental land use (ocean beach erosion)
5	Immediately northeast of part of Test Area 3	Environmental land use (Dusky Seaside Sparrow habitat)

NOTE: A small part of Test Area 2 overlaps the western part of Test Area 1.

4
RADAR DATA GATHERING

A radar data-gathering flight was made during the mid-morning of October 7 to image Test Areas 1, 2, and 3; two attempts were made to image Test Area 1. Ground truthing was also started the same day.

Because of adverse weather, a second data-gathering flight during the morning of October 12 had to be terminated after imaging only Test Area 1. Test Areas 4 and 5, though interesting, had the lowest priorities of all the test areas and unfortunately could not be imaged during this experiment. The characteristics of the imaging flights are given in Table 2.

5
QUALITY OF THE RADAR IMAGERY

The multiplexed SLAR used to obtain imagery of Brevard County is designed to image a swath of terrain approximately 3.5 miles wide paralleling the aircraft flight path. Four simultaneous radar images are ultimately produced: like- and cross-polarized images for both X- and L-band wavelengths.

TABLE 2. CHARACTERISTICS OF MULTIPLEXED SLAR IMAGING FLIGHTS, BREVARD COUNTY, FLORIDA (1973)

Test Area	Date Imaged	Pass No.	Altitude of Airplane Above Mean Sea Level (ft)	Slant Range Distance to Near Edge of Imagery (ft)	Depression Angles		Length of Imaged Area (miles)	Slant Range Swath Width (ft)	Flight Direction, True Azimuth	Radar Look Direction, True Azimuth	Transmitting and Receiving Polarizations, Each Wavelength
					Near Range	Far Range					
1	Oct. 7, 1973	1	6500	13,200	30°	12°	16	18,000	356°	86°	*HH, HV
1	Oct. 7, 1973	4	9500	24,300	23°	13°	16	18,000	356°	86°	HH, HV
2	Oct. 7, 1973	2	8500	17,300	25°	14°	71	18,000	341°	71°	HH, HV
3	Oct. 7, 1973	3	9500	24,300	23°	13°	50.5	18,000	164°	254°	HH, HV
1	Oct. 12, 1973	1	6500	13,200	30°	12°	16	18,000	356°	86°	HH, HV

*H = horizontal polarization
V = vertical polarization
The first letter represents the transmitting polarization, the second letter indicates the receiving polarization.

The slant-range scale of the X-band imagery in this report is approximately 1:35,000 in the range or cross-track direction (perpendicular to the aircraft flight path and parallel to the radar look direction) and approximately 1:33,000 in the azimuth or along-track direction (parallel to the aircraft flight path). The slant-range scale of the L-band imagery is approximately 1:36,500 in both the range and azimuth directions.

Intensity bands running across the X-band imagery from near range to far range may be seen at random locations on the radar imagery of all three test areas. These bands are caused by random variations in X-band antenna alignment which allow the antenna gain along the line of sight to the target to vary. This situation has since been corrected, but the necessary work had not been completed when the Brevard County data were recorded.

The resolution of radar imagery in this report is intended to be approximately 30 ft in both the azimuth and range directions. Resolution is defined as the half-power width of the main lobe of diffraction-limited image components.

6
AERIAL PHOTOGRAPHY AND THERMAL INFRARED IMAGERY

6.1 INTRODUCTION

The task of obtaining black and white aerial photography and broad band 8-12.5 micron thermal infrared (IR) imagery of the test areas in Brevard County that would be imaged during the SLAR flights was subcontracted, by ERIM, to MAPCOtec, INC., Daytona Beach, Florida. The aerial photography and thermal IR imagery were to be obtained as soon as possible after the SLAR imaging flights. However, because of special constraints (such as cloud cover, time of day, etc.) placed by ERIM upon the gathering of the aerial photography and thermal IR imagery, poor weather delayed collection of these two types of imagery until near the end of October.

6.2 AERIAL PHOTOGRAPHY

On October 31, between 4:00 and 5:00 P.M. (EST), excellent black and white aerial photography was obtained at Test Areas 1, 2, and 3. The photography has a scale of almost exactly 1:24,000 and approximately 60 percent end overlap between successive photographs. All the photographs are cloud-free except for scattered clouds visible on the photographs at the northern end of the photographic coverage of Test Area 3, and scattered clouds northeast of Titusville in Test Area 2.

6.3 THERMAL IR IMAGERY

On October 27, thermal IR imagery was obtained of Test Areas 1, 2, and 3. All the imagery was gathered within approximately two hours after sunrise (6:31 A.M. EDT at KSC). This was

soon enough after sunrise so that the ground temperatures had not yet become roughly equilibrated. The thermal IR imagery of the three test areas has several gray tones on it; these range from the darkest and coldest features (shorter vegetation and certain cultural features) to the lightest and warmest features (water bodies). This indicates that there still was a large thermal contrast at ground level. There was a light ground fog in all three test areas.

7
GROUND TRUTH PROCEDURES

The three test areas imaged by radar were ground truthed from October 7 (the day of the first radar flight) through October 16, 1973. Objectives of this ground truthing were threefold: (1) Document conditions in the test areas during the radar data gathering for each of the four earth resources purposes. (2) Ground truth any places or features which had unexpected or interesting returns on the radar imagery. (3) Make field measurements of the complex dielectric constant of vegetation using portable microwave equipment.

Most of the ground truthing was done on foot, although a small amount was by observation from a car. Almost all of Test Area 3 was ground truthed from a boat. Obviously, because of the limited time available for ground truthing and the large areas to be covered, only a relatively small number of places and features could be ground truthed.

8
RADAR REFLECTOR STUDIES

ERIM and KSC cooperated with Mr. Gene Sivertson of the Shuttle Experiments Office, NASA Langley Research Center (LaRC) in his study of the radar return from experimental radar reflectors. Inflatable type reflectors and 14 rigid, trihedral corner reflectors used to determine relative calibration curves were placed by LaRC personnel on Merritt Island in the northern part of Test Area 1. The reflectors were successfully imaged during the October 12 imaging mission.

9
METHODS OF ANALYZING THE IMAGERY

The radar imagery and ground truth data were interpreted and analyzed mainly to determine the feasibility of using multiplexed X- and L-band SLAR for each of the four earth resources purposes. This section discusses how the analysis was done by the Radar Applications Section of ERIM's Radar and Optics Division.

The usefulness of the multiplexed and SLAR for the various earth resources purposes was analyzed using photographic prints of the radar imagery; the ground truth field notes and color photographs; the 1:24,000 scale black and white aerial photographs and thermal IR imagery gathered by MAPCOtec, INC.; 1:4800 scale enlargements of 1969 black and white aerial photographs; and 7.5 minute topographic maps.

This was the first time that multiplexed SLAR imagery, aerial photographs, and thermal IR imagery of a region were gathered within such a short time period (25 days). Therefore, although the interpretation of the multiplexed SLAR imagery was the major task, comparisons were made between the radar imagery, 1:24,000 scale aerial photography, and thermal IR imagery as to the information about specific features contained in each type of imagery. The various types of imagery were interpreted with the unaided eye, using primarily tone and texture as identification parameters with shape, pattern, size, and location as secondary identification parameters. The imperfections of the radar image were taken into account during the analysis. Because of these imperfections, no quantitative analysis (densitometer measurements, etc.) of the radar imagery was attempted.

The SLAR imagery, aerial photographs, and thermal IR imagery were examined to determine the qualitative tone and texture of many rural land-use features imaged during the experiment. Also, in many instances the various types of imagery were examined to determine with what other feature(s) a particular feature could be confused. Very few attempts were made to evaluate the appearance of a given feature on the radar imagery relative to the radar look direction, incidence angle, etc., or to determine what radar-return parameters contributed to the return from a given feature.

10
FEASIBILITY OF USING MULTIPLEXED SLAR TO DETECT POOLS OF WATER UNDER STANDING VEGETATION

One of the purposes of this experiment was to determine the feasibility of using multiplexed SLAR to detect pools of water under standing vegetation and particularly under canopies of dense vegetation. This was done in the hope that multiplexed SLAR could aid the Brevard Mosquito Control District (BMCD) in looking for temporary pools of water in which the flood-water mosquito larva spends its part of the mosquito life cycle.

The idea behind this part of the experiment was that the multiplexed SLAR would either directly or indirectly detect the pools of water under standing vegetation. Direct finding of the pools would have meant that the SLAR wavelengths penetrated the covering vegetation to reflect from the water. Indirect finding of the pools would have meant that the SLAR wavelengths did

not penetrate the covering vegetation, but that there was a different radar reflection from the vegetation covering the pools of water than from vegetation not covering pools.

There are no indications that either the X- or L-band wavelengths penetrated the dense canopies and were specularly reflected away from the surface of the pools. Also, on the parallel- and cross-polarized imagery of each wavelength, the returns from the trees above the pools were no different than those from trees not standing in water. On neither the aerial photographs nor the thermal IR imagery can the pools be seen, and the areas where the pools exist under the canopies do not look different on either type of imagery than dense tree areas where there are no pools.

The results from this part of the experiment are rather definite. The pools of water under canopies of dense vegetation cannot be detected, either directly or indirectly, by either the X- or L-band SLAR at moderate and low depression angles. It might be possible at very steep depression angles to detect the pools with L-band or longer wavelength SLAR, but it is doubtful. Apparently pools of water in areas of low vegetation such as ICP are not indicated, either directly or indirectly, on either the X-band or L-band imagery.

11
FEASIBILITY OF USING MULTIPLEXED SLAR FOR LAND-USE PLANNING

11.1 INTRODUCTION

Many land-use classification systems exist at the present time, and are used by different federal, state, and local governmental agencies. For many years land-use classification was based on data obtained by ground observation and enumeration, complemented by data obtained from conventional aerial photography. Recent development of other remote-sensing techniques such as multispectral scanning, spacecraft photography, and SLAR has now made it possible to inventory the land use of large areas in a short period of time. Also, data processing techniques allow the storage of large quantities of detailed information that can be used in several ways to meet specific needs. In the future, land-use classification will be accomplished largely by automatic data processing of remote-sensing imagery.

Several problems exist in defining a land-use classification system for use with remote-sensor data: (1) Land-use patterns change and evolve with time. Consequently, no one detailed classification system will be adequate for more than a relatively short period of time. (2) Different types and amounts of land-use information are obtained by the various remote sensors because of their different capabilities for data gathering. (3) What is meant by "land use" is not clearly defined. (4) The classification system must allow for the classification of all parts of the area under study and should also provide a unit of reference for each land use.

Assuming that different sensors will provide information for different levels of classification, Anderson, et al., (1972) anticipate the relations given in Table 3.

TABLE 3. CLASSIFICATION LEVELS OF LAND USE

Classification Level	Source of Information
I	Satellite imagery, with very little supplemental information
II	High-altitude and satellite imagery combined with topographic maps
III	Medium-altitude and remote sensing combined with detailed topographic maps and substantial amounts of supplemental information
IV	Low-altitude imagery with most of the information derived from supplemental sources

These four different levels of classification have been developed for imaging sensors which measure angles, such as camera systems and scanners; for these sensors the scale and resolution of the imagery decrease with range, which in this case is altitude above ground.

Radar measures distances, and its resolution is essentially independent of range and radar wavelength. Land-use information obtained by an analysis of SLAR imagery does not readily fit into the classification levels discussed above because of the radar scales and resolution involved. Much of the land-use classification from this SLAR imagery should only be possible at Levels I and II. However, the resolution of the Brevard County SLAR imagery is approximately 30 ft×30 ft, and this enables land-use classification at Levels III and IV to be done from the multiplexed radar imagery.

11.2 LAND-USE CLASSIFICATION SYSTEM USED

We have followed the land-use classification system of Anderson, et al (Table 4), during this study, even though there are problems in doing so: (1) The system was developed specifically for imaging sensors which measure angles; it was not developed for radar. (2) Some features can be recognized and classified on the SLAR imagery at a finer scale and resolution than allowed for in the classification system. The classification system is provisional and has not yet been widely tested. (4) Not enough data is presently available to determine, using the classification system, the accuracy of land-use interpretation on imagery of the various sensors. (5) Not all of the categories of the system are represented in the test areas, and some land uses are present in the test areas that are not provided for in the classification system.

11.3 COMPARISON OF URBAN LAND-USE CLASSIFICATION FROM SLAR IMAGERY AND AERIAL PHOTOGRAPHY

Land-use maps based upon the visual interpretation of the multiplexed SLAR imagery were prepared of parts of two urban areas within Brevard County, namely the Titusville and Mel-

TABLE 4. LAND-USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA
(From Anderson, et al. 1972)

Level I	Level II
1 Urban and Built-up Land	
	.1 Residential
	.2 Commercial and Services
	.3 Industrial
	.4 Extractive
	.5 Transportation, Communications, and Utilities
	.6 Institutional
	.7 Strip and Clustered Settlement
	.8 Mixed
	.9 Open and Other
2 Agricultural Land	
	.1 Cropland and Pasture
	.2 Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas
	.3 Feeding Operations
	.4 Other
3 Rangeland	
	.1 Grass
	.2 Savannas (Palmetto Prairies)
	.3 Chaparral
	.4 Desert Shrub
4 Forest Land	
	.1 Deciduous
	.2 Evergreen (Coniferous and Other)
	.3 Mixed
5 Water	
	.1 Streams and Waterways
	.2 Lakes
	.3 Reservoirs
	.4 Bays and Estuaries
	.5 Other
6 Nonforested Wetland	
	.1 Vegetated
	.2 Bare
7 Barren Land	
	.1 Salt Flats
	.2 Beaches
	.3 Sand Other Than Beaches
	.4 Bare Exposed Rock
	.5 Other
8 Tundra	
	.1 Tundra
9 Permanent Snow and Icefields	
	.1 Permanent Snow and Icefields

Level I land-use categories are indicated in this report by integers such as 1. Level II categories are indicated by decimal suffixes such as .1. Thus, a number such as 2.1 gives both the Levels I and II classifications.

bourne metropolitan regions. These land-use maps then were compared with similar land-use maps based upon the visual interpretation of the 1:24,000 scale black and white aerial photography in order to determine the accuracies of the urban land-use identifications made from the SLAR imagery.

Residential areas are the predominant type of urban land use in the areas studied. Locally, there are misinterpretations on the SLAR imagery of non-residential areas as residential areas, and vice versa, but generally are defined on SLAR. Many of the houses commonly in residential areas appear as point returns. Shopping centers generally are easily identified on the SLAR

Shopping centers generally are easily identified on the SLAR imagery, particularly X-band. Basically, a shopping center is a large, flat, smooth parking lot associated with a number of buildings. There are no radar returns from the parking lot surfaces, but there are returns, commonly prominent ones, from the buildings.

Strip and Clustered Settlements are difficult to identify on the SLAR imagery; parts of them are often misidentified as residential or various commercial areas. They generally appear on the radar imagery as a linear cluster of bright point returns along a highway, railroad track, etc.

11.4 RURAL LAND USE

11.4.1 INTRODUCTION

For the purposes of this report, rural land use has been defined as land use outside the urban areas. In this study, rural land use is concerned with Level I categories 2 (Agricultural Land) through 6 (Nonforested Wetland), but not all Level II categories of these Level I classifications are present in the test areas. Water resources and nonforested wetland are discussed in Sections 12 and 13.

The purpose of this experiment was to determine the feasibility of using multiplexed SLAR, among other purposes, for rural land-use planning. Specific objectives of this part of the study are to:

(1) Determine with what other rural land-use categories or features a particular rural category or feature could be confused on the various types of imagery, and how to discriminate them.

(2) Determine at what level(s) rural land use in the test areas can be classified on the multiplexed radar imagery.

(3) Determine whether the major differences in appearance on the multiplexed SLAR images of the various vegetation types in the test areas are primarily wavelength or polarization differences.

Several different types of vegetation, both on land and in the water, can be differentiated and mapped on the multiplexed radar imagery by the relative heights, densities, surface roughnesses, etc., of the vegetation. The vegetation type is not directly sensed by the SLAR.

11.4.2 IMPROVED CATTLE PASTURE

Improved cattle pasture (ICP) is an area from which most of the native vegetation has been removed by man, the land made essentially level, and then re-sodded with "grass." Trees commonly are left standing in the ICP, both as isolated trees and in small scattered stands. Some of the improved cattle pastures have been cropped to improve their acceptability to the cattle. The ICP regions were identified using the SLAR imagery, 1:24,000 scale aerial photographs, the thermal IR imagery, and available ground truth. Most of the improved cattle pastures studied are in Test Areas 2 and 3, and are indicated by the number 2.1 on the plates of the various imagery.

11.4.3 CITRUS GROVES

Citrus groves are extensively present in Test Areas 1 and 2 on both sides of the Indian River. We were not able to differentiate between orange and grapefruit groves on the various types of imagery and thus the general term citrus groves is used in this report. Citrus groves are labeled 2.2 on the plates 1A and 1C.

The trees in the groves are planted in one or more row directions. In many groves the rows approximately paralleling the azimuth direction can be seen on the 30 × 30 ft resolution X-band imagery, and locally the rows approximately paralleling the range direction also can be seen on the X-band imagery. It generally takes a several-power magnification to see the rows on the X-band imagery. Where the rows can be seen on any of the types of imagery, they positively identify the area as citrus groves. The linear boundaries and geographic locations of the citrus groves help to identify them on the different types of imagery.

11.4.4 RANGELAND

Several different types of Rangeland can be differentiated on the multiplexed SLAR imagery. Multiplexed SLAR is the single best sensor of the three to differentiate and map Level II categories of Rangeland. General Rangeland is labeled 3 on the plates 1A and C and plates 5A, and C.

A type of rangeland, unimproved cattle pasture is used for cattle grazing. It usually consists of native vegetation several feet high, commonly is located near rivers, and when flooded becomes a type of marshland. Areas interpreted as unimproved cattle pasture are labeled A on Plates 5A, and C. On the three types of imagery, unimproved cattle pasture is extremely difficult to distinguish from other types of vegetation.

11.4.5 FOREST LAND

Forest Land is labeled 4 on the plates of the various imagery. It is extremely difficult to determine on the radar imagery whether tree areas are Deciduous, Evergreen, or Mixed. It was not possible to identify the tree type (oak, palm, pine, etc.) except on the basis of the geometric considerations of the tree stands. Linear belts of Australian pines generally can be identified on the radar imagery, especially when they are oriented at a high angle to the radar look direction.

Qualitative estimates of the densities of tree areas can be made from the radar imagery (particularly the L-band imagery) as well as from the aerial photographs.

12
FEASIBILITY OF USING MULTIPLEXED SLAR FOR WATER RESOURCES MANAGEMENT

12.1 INTRODUCTION

Water resources encompass the Level I categories 5, Water, and 6, Nonforested Wetlands. However, many features pertinent to water resources, such as islands, shorelines, floating vegetation, and diking systems do not readily fit into the two Level I categories mentioned above. For this reason, water resources are discussed under various subheadings.

12.2 OPEN WATER AREAS

Open water areas are standing or flowing water bodies without an appreciable amount of either standing or floating vegetation.

Boundaries of open water areas can be seen quite well on the radar imagery and are clearly delineated except where the vegetation around the water body is very low and uniform in height.

The aerial extent of open water bodies can be determined and surface areas can be calculated using the radar imagery even though locally there is distortion in the shape of the water body, especially in the near range of the imagery. The radar imagery and early-morning thermal IR imagery yield no information about the relative depth of water, bottom features, or sediment content of open water areas, but in many instances the aerial photography does.

The tonal and textural differences on the SLAR imagery of Lake Poinsett (see Plates 5A-D) may be indicative of surface wave action.

Flat or essentially flat areas consisting of exposed sediments whose particle sizes are less than the radar wavelength can be confused with open water areas on both the X- and L-band imagery, but can be distinguished from water bodies on the aerial photographs and thermal IR imagery. There might be some confusion also on the L-band imagery, but not on the X-band imagery, if there was scattered low vegetation growing on the sediments.

In general, water bodies of all shapes and trends, and larger than a "minimum" size can be seen equally as well on the X-band imagery, aerial photographs, and thermal IR imagery.

12.3 ISLANDS

On both the radar imagery and the thermal IR imagery, only the parts of islands above water are visible. On the aerial photographs, both the parts of islands above water and those covered by shallow water are visible.

The radar return from islands is mainly, if not entirely, from the vegetation growing on the islands, and thus is greatly dependent upon the vegetation types present as well as the relative heights of the vegetation. Generally, islands in the Indian River appear light-toned with rough texture on both polarizations of the X- and L-band imagery. It should be noted that only one wavelength and polarization is needed to identify islands.

Islands cannot be positively differentiated on the radar imagery from masses of floating vegetation, but generally can be differentiated on the aerial photographs.

12.4 SHORELINES

Radar, particularly at X-band and shorter wavelengths, generally is an excellent indicator of the water-land boundary. The boundary between water and low vegetation that is even in height cannot be located on the L-band imagery, but can be seen on X-band imagery.

Radar imagery is well suited for determining how much of low-lying islands and shorelines is above water at different flood stages. As an all weather sensor, radar is capable of imaging through clouds, thus it can monitor floods as they occur.

12.5 NAVIGATION AIDS, POWER POLES, AND DOCKS IN THE INDIAN RIVER

Navigation aids (buoys, fixed signs, etc.) can be seen as point target returns on both the X- and L-band radar imagery, but cannot be seen on the thermal IR imagery and only infrequently, if at all, on the aerial photographs. The navigation aids have brighter returns on the L-band imagery than on the X-band imagery.

Transmission line poles, both metallic and wooden, in water bodies can be clearly seen on both the X- and L-band imagery as separate distinct point targets. They generally cannot be seen on the aerial photographs except for an infrequent pole or two or their shadows. The poles are not visible on the thermal IR imagery.

Docks for pleasure boats on both sides of the Indian River can be seen on the X-band parallel-polarized imagery, but generally not on the X-band cross-polarized imagery. Some docks are visible on the L-band parallel-polarized imagery, but are not as well defined as on the X-band parallel-polarized imagery. Generally, the docks are not visible on the L-band

cross-polarized imagery or on the thermal IR imagery. The aerial photography clearly defines each pleasure dock.

12.6 DIKING SYSTEMS

Diking systems ard accompanying ditches are used for flood control as well as irrigation purposes. The dikes consist of a linear pile of earth material standing several feet above the terrain with ditches, commonly full of water, on one or both sides. Often vegetation and an access road are on top of the several feet to few tens of feet wide dikes.

Typical dikes are labeled D on Plates 1A and C. Dikes give a moderately strong return on both the X- and L-band radar imagery when their orientation is essentially perpendicular to the radar look direction, and a moderate return when oriented essentially parallel to the look direction. Those essentially perpendicular to the look direction present a steep sloping surface that the radar beam reflects from back to the antenna. However, most of the radar return comes from the vegetation growing along the banks and top of the dikes; therefore, the more vegetation and the more uneven in height the vegetation on the bank, the stronger the radar return. Quite commonly, the ditch (with or without water) alongside the dike is visible on the radar imagery.

12.7 AQUATIC VEGETATION

The water hyacinths generally stand 1 to 3 ft above the water. They commonly float in the water and migrate along the St. Johns River due to the action of wind and water currents. However, large patches of them also are stationary. The hyacinths generally are clearly defined on the radar imagery, and areas of them are labeled C on Plates 5A and C. The hyacinths generally are well indicated on both the aerial photographs and the thermal IR imagery. Hyacinths are a hazard to boat navigation, as well as choking current flow. Therefore, monitoring of their growth and migration is of importance.

The water lilies that were ground truthed have 5 inch diameter pads and extend up to 3 inches out of the water. The pads of the water lilies are faintly indicated on both the X- and L-band imagery (D on Plates 5A and C). These pads are not seen on the thermal IR imagery and only faintly seen on the aerial photography.

An arc of reeds standing up to 5 ft out the water is labeled E on Plates 5A and C. Individual reeds are spaced a few to several inches apart, but commonly touch each other when the wind blows. The reeds are clearly visible on all the multiplexed SLAR images, only faintly visible on the aerial photography, and not visible at all on the thermal IR imagery.

In this instance, the water hyacinths, water lilies, and reeds can be differentiated only on the multiplexed SLAR imagery. It is important to note that it is necessary to use both polarizations of both the X- and L-band imagery for the differentiation.

12.8 MARSH REGIONS

Marshes are part of category 6.1, Vegetated Nonforested Wetland, and in the test areas are located on flat terrain. Marshes are considered to be perennial areas that contain appreciable amounts of both water and vegetation (predominantly reeds). Individual marshes can be relatively hard to definitely identify using any one of three sensors individually because the marshes vary so greatly in terms of the vegetation/water ratio. The great majority of all marshes can be identified on the multiplexed SLAR imagery.

Marsh areas can be located and identified and their areal extents and boundaries determined with a high degree of confidence using a combination of multiplexed SLAR and thermal IR imagery. The geographic location of most marshes aids in their identification on the aerial photographs, as it also does on the other types of imagery.

13
FEASIBILITY OF USING MULTIPLEXED SLAR FOR DETERMINING DRAINAGE PATTERNS

Generally, the drainage patterns in the Florida test areas can be delineated as well on the SLAR imagery as on the aerial photography. The stream patterns can be seen on the thermal IR imagery also, but locally cannot be delineated and traced as well. X-band imagery is better than L-band imagery for tracing the stream patterns.

The channels that are choked with aquatic vegetation can be identified quite readily on the aerial photography, thermal IR imagery, and the X-band imagery (F on Plates 5A). Locally, on the L-band imagery, it is difficult to distinguish the vegetation-choked channels from other vegetation features. In general, either X-band or shorter wavelength SLAR or aerial photographs should be used for drainage basin analysis. L-band radar imagery and thermal IR imagery add supplemental information, but should not be the primary data sources for drainage basin analysis.

14
ANALYSIS OF THE COMPLEX DIELECTRIC CONSTANT MEASUREMENTS OF MARSH VEGETATION

14.1 INTRODUCTION

In addition to visual interpretation techniques as described in previous sections, considerable information can be obtained from radar imagery (as well as from imagery provided by other sensors) by using statistical techniques to analyze sections of the imagery or by using deterministic measures. Statistical methods are recognition schemes based on statistical anal-

ysis of the radar return from a given area. When a statistically determined set of parameters has been "learned," say from a given test site, other such sites on the imagery can be recognized.

Deterministic techniques require both multi-channel data and a defined model of the area of interest. For example, a particular class of terrain types may have a roughness scale such that a scattering model would predict that the ratios of backscattered power for the two particular wavelengths should fall within certain limits. The ratio values delineate the class.

14.2 SITES OF THE MEASUREMENTS

Two test sites were selected for dielectric constant measurements. There is considerable contrast between the X- and L-band parallel-polarization images of the two areas. A wavelength dependency in the scattering properties of each area is thus indicated.

14.3 MEASUREMENTS

Ground observations of the following types were made at each of the two test sites: (1) photographic, consisting of color photographs of the sites; (2) electrical, consisting of dielectric constant measurements at frequencies of 100 MHz and 9.3 GHz; and (3) physical measurements of dimensions and general observations.

Both test sites consist of tall "grass" extending out of the water. Heights averaged about 4 ft, the diameter of the "stalks" is approximately 4 in., and the diameter of the individual stems is approximately 0.4 in. Dielectric constant measurements were made of the upper and lower stalk for each sample gathered.

The dielectric constant measurements are summarized in Table 5.

14.4 DETERMINISTIC MODEL

Table 6 gives the associated radar parameters calculated using the measured dielectric constant and physical dimensions from the two test sites.

Qualitatively, the model's description of the backscatter is in agreement with that observed from the radar imagery. For this particular situation, similar areas observed on the imagery can, with reasonable confidence, be said to be identical to the two test sites.

15
PRINCIPAL CONCLUSIONS

These conclusions refer specifically to this experiment, though in many cases they also are more generally valid. They are grouped to correspond to various sections of the discussion, rather than being listed in order of importance.

TABLE 5. SUMMARY OF DIELECTRIC CONSTANT MEASUREMENTS OF MARSH VEGETATION

Section of Grass	Relative Dielectric Constant ϵ		Loss Tangent ($\tan \delta$) at 9.3 GHz
A	1:00 MHz	9.3 GHz	>0.33
	4.5	20.0	
	3.0		
	4.1		
B	2.6	12	>0.1
	1.92		
	3.2		
	2.6		

TABLE 6. CALCULATED VALUES FOR RADAR BACKSCATTER CROSS-SECTION

Cross-Section of Thin Cylinder* (σ_{cyl})		Total Backscatter Predicted by Model (σ_o)	
9.3 GHz	1.2 GHz	9.3 GHz	1.2 GHz
0.2 m^2	0.8 m^2	0.064	0.008
*d = 0.4 in. ℓ = 4 ft			

15.1 GENERAL CONCLUSIONS

A. Significantly more information for urban and rural land-use planning and for water resources management was obtained from the multiplexed X- and L-band SLAR imagery than could have been obtained from the imagery of either wavelength alone.

B. Once the radar imagery has been gathered, it can be processed and returned to field personnel within a short enough period of time so that timely ground truthing can be done for many short-lived phenomena.

C. On the multiplexed SLAR imagery the major differences in appearance of an urban or rural land-use category or feature or a water resources feature are primarily wavelength differences, not polarization differences. However, the use of all four

radar images sometimes is necessary to positively differentiate between certain features.

D. Radar interpretation should be performed at the finest resolution available.

E. Multiplexed SLAR, large-scale black and white aerial photography, and thermal IR imagery each provide certain types of information concerning a specific earth resources problem or feature, and complement and supplement one another.

15.2 DETECTION OF POOLS OF WATER UNDER STANDING VEGETATION

A. Neither X- nor L-band SLAR at moderate and low depression angles can directly or indirectly detect pools of water under canopies of dense vegetation.

B. Apparently neither X- nor L-band SLAR at moderate and low depression angles can directly or indirectly detect pools of water in areas of low vegetation where the relatively dense vegetation is intimately mixed with the water and projects up to several inches above the water.

15.3 LAND-USE PLANNING

A. General

(1) Many of the Levels I and II urban and rural land-use categories present in the test areas can be identified (or at least differentiated) and mapped on the multiplexed SLAR imagery.

(2) Some Level III, and possibly even Level IV, land-use identification can be classified on the SLAR imagery.

(3) Higher levels of land-use classification can be accomplished using multiplexed SLAR imagery than can be accomplished using single-wavelength SLAR imagery.

(4) The level of land-use classification using radar imagery is independent of the distance of the radar from the imaged terrain, unlike other remote sensors.

(5) The present classification systems should be modified to readily accept the types of land-use information that can be obtained by SLAR, rather than by angle measuring sensors.

B. Urban

(1) Radar imagery is much better for identifying general areal land use than for identifying land use at particular points.

(2) Large-scale aerial photography allows finer detailed and more accurate identification of urban land use than from the 30 ft × 30 ft-resolution multiplexed SLAR imagery.

(3) Locally, residential areas are confused on the radar imagery with non-residential areas, although generally the differentiation can be made.

(4) Areas that are heavily wooded and/or covered by lower vegetation, can be confused among themselves on the radar imagery as well as with Rangeland and Forest Land.

(5) Commercial areas locally were confused on the radar imagery with Strip and Clustered Settlements.

(6) Institutional areas were not confused on the radar imagery with Commercial areas and Residential areas as often as might be expected. However, it is extremely difficult to identify the type of institution (school, hospital, etc.).

(7) Strip and Clustered Settlements are difficult to identify on the radar imagery; parts of them are commonly misidentified as residential or various commercial areas.

C. Rural

(1) Levels I and II land use can be identified as well and often better on the multiplexed radar imagery as on the large-scale aerial photography.

(2) Several different types of vegetation, both on land and in the water, can be differentiated and mapped on the multiplexed radar imagery by the relative heights, densities, surface roughnesses, etc., of the vegetation.

(3) Multiplexed SLAR is a good indicator of the relative heights of vegetation. Using both the X- and L-band imagery, the relative heights of vegetation differing only 18 to 24 inches in height can be discerned.

(4) Improved cattle pasture (ICP) can be confused with Rangeland and Nonforested Wetland on both the X- and L-band imagery. ICP locally can be confused with citrus groves on the radar imagery, but the row patterns in the groves, if visible on the imagery, will enable the ICP and citrus groves to be differentiated.

(5) Citrus groves can be confused with Nonforested Wetland on the X-band imagery, but not on the L-band imagery. There is great potential for distinguishing the four growth stages of the groves on the multiplexed radar imagery.

(6) SLAR is the single best sensor to differentiate and map the distributions of Level II categories of Rangeland.

(7) X- and L-band radar wavelengths will not significantly penetrate dense areas of trees. The diffuse return at each wavelength comes from the upper part of the tree canopy.

15.4 WATER RESOURCES MANAGEMENT

A. Open Water Areas

(1) Water bodies of all shapes, trends, and larger than a "minimum" size can be seen equally well on the X-band imagery, aerial photographs, and thermal IR imagery.

(2) Radar imagery and early-morning thermal IR imagery yield no information about the relative depth of water, bottom features, or sediment content of water, but aerial photographs can.

B. Islands

(1) Islands cannot be positively differentiated on the radar imagery from masses of floating vegetation, but generally can be differentiated on the aerial photographs.

C. Shorelines

(1) Radar, particularly at X-band, is an excellent indicator of the water-land boundary.

(2) Radar imagery is well suited for determining how much of low-lying islands and shorelines is above water at different flood stages of a river or lake.

D. Navigation Aids, Power Poles, and Docks

(1) Navigation aids and power poles in water bodies can be seen on both the X- and L-band imagery, infrequently on aerial photographs, and never on the thermal IR imagery.

(2) Docks can be seen on some of the radar images as well as on aerial photographs.

E. Diking Systems

(1) Dikes, and commonly the accompanying drainage ditches, can be seen and traced on both the X- and L-band imagery, regardless of their orientation to the radar look direction.

F. Aquatic Vegetation

(1) The three types of water vegetation can be differentiated only on the multiplexed radar imagery. Water hyacinths, water lilies, and small patches of reeds are visible on both the X- and L-band imagery. The hyacinths generally are visible on both the aerial photographs and thermal IR imagery. The water lilies and reeds are not

visible on the thermal IR imagery and are only faintly indicated on the aerial photographs.

G. Nonforested Wetland (Marshes)

(1) Because they vary so greatly in terms of their vegetation/water ratio, individual marshes can be relatively hard to definitely identify using any one of the three sensors individually. The great majority of the marsh areas can be identified on the multiplexed SLAR imagery. Using both the multiplexed SLAR and thermal IR imagery, virtually all the marsh areas can be identified and their areal extent and boundaries determined.

(2) There is no significant penetration of marsh vegetation at X-band wavelength. The L-band wavelength apparently penetrates marsh reeds standing up to 5 feet out of the water, the return probably indicates the height and density of the vegetation.

15.5 DETERMINATION OF DRAINAGE PATTERNS

A. Drainage patterns, including both different orders of streams as well as different types of drainage patterns, can be readily seen on either the X- and L-band imagery, but are better determined on the X-band imagery.

B. Generally, the drainage patterns, including braided ones, can be delineated as well on the SLAR imagery as on the aerial photographs.

C. Channels that are choked with floating vegetation can be identified quite readily on the aerial photography, thermal IR imagery, and the X-band imagery.

D. The stream channels can be most readily traced through marsh areas on the areal photography and the X-band imagery.

E. In general, either X-band SLAR or aerial photograph is the preferred sensor to use for drainage basin analysis.

16
RECOMMENDATIONS FOR FUTURE WORK

The recommendations include those for the continued analysis of the Brevard County imagery already acquired, as well as long-term recommendations, most of which require additional radar imaging. Items in the following enumeration are not necessarily listed in order of importance.

16.1 CONTINUED ANALYSIS OF THE PRESENT BREVARD COUNTY IMAGERY

A. Short-Term Applications

(1) Make land-use maps of the three Brevard County test areas at the most detailed level(s) of classification possible. The maps should be made using data from the multiplexed SLAR imagery, the large-scale aerial photography, the thermal IR imagery, and 7.5 minute topographic maps.

(2) Prepare a basic environmental geologic map and several special-use environmental maps of Test Area 2 showing the different environmental and resource units. These maps would be very similar to those of the Environmental Geologic Atlas of the Texas Coastal Zone.

(3) Using both the aerial photographs and the radar imagery, determine the distribution of the four growth stages of the citrus groves.

(4) Map, if possible, the distribution of unimproved cattle pasture, using all three types of imagery.

(5) Using all the three types of imagery, attempt to classify Forest Land into the Level II categories Deciduous, Evergreen, and Mixed.

(6) Inventory the natural and man-made open water areas in all three test areas.

(7) Map the various stream channels and up-date the most recent topographic maps.

B. Basic Research

(1) Determine for each wavelength how the transmitting and receiving polarizations, the orientation of the feature to the radar look direction, the depression angles used, the incidence angles, etc., influence the recognition of specific features on the radar imagery.

(2) Determine what radar-return parameters contribute to the radar return from a given feature.

(3) Determine, if possible, how to distinguish on each of the three types of imagery between the Levels I and II categories that can be confused with each other.

(4) Determine the accuracy of recognition under different terrain conditions on the various types of imagery of at least the Levels I and II categories present in the test areas. Also determine the minimum size(s) of the various categories and features that can be accurately recognized on the three types of imagery.

(5) Determine what specific information about various categories and features can be obtained from the three types of imagery.

(6) Begin quantitative analysis, where feasible, of the radar imagery, including digital automatic recognition.

(7) Compare the land-use maps of the test areas made from the three types of remote-sensing imagery against the land-use maps of those areas compiled from "conventional" sources.

(8) Determine the maximum vegetation/water ratio that will allow a marsh to be identified on the multiplexed radar imagery.

(9) Determine the ease and accuracy with which specific features on the radar imagery can be identified by inexperienced interpreters.

16.2 LONG-TERM RECOMMENDATIONS

A. Periodically radar image the marshes in the test areas in order to determine how the marshes are growing, being enchroached upon, or being drained.

B. Monitor ocean beach erosion, deposition, and distribution of beach sediments, by periodically imaging proposed Test Area 4 with the multiplexed SLAR

C. Radar image proposed Test Area 5 to help determine the habitat preferred by the Dusky Seaside Sparrow, and the distribution of salt pans and marl regions.

D. Radar image the St. Johns River at different water levels.

E. When radar imaging a region, transmit vertically as well as horizontally (now only possible on successive passes), and use different depression angles and look directions.

F. Modify existing systems for classifying land-use information obtained mainly by remote-sensing techniques.

G. Determine how multiplexed SLAR can be used to identify urban land use for communities of various sizes, populations, and densities.

H. Determine how multiplexed SLAR can be used to map Rangeland vegetation communities during their various growth stages.

I. Determine the range of differences in relative heights of different vegetation communities that can be determined on the multiplexed SLAR imagery.

J. Inventory marsh regions in Florida and the southeastern United States.

K. Begin automatic data processing of good quality radar imagery.

L. Establish an agricultural test site in the southeastern United States to begin to determine how multiplexed SLAR can be used to identify various crops during their growth stages, including those crops indigenous to the southeastern United States. Work also should continue with the agricultural test site established in southeastern Michigan in order to determine the preferred transmitting polarization(s), depression angles, and look direction(s) that should be used.

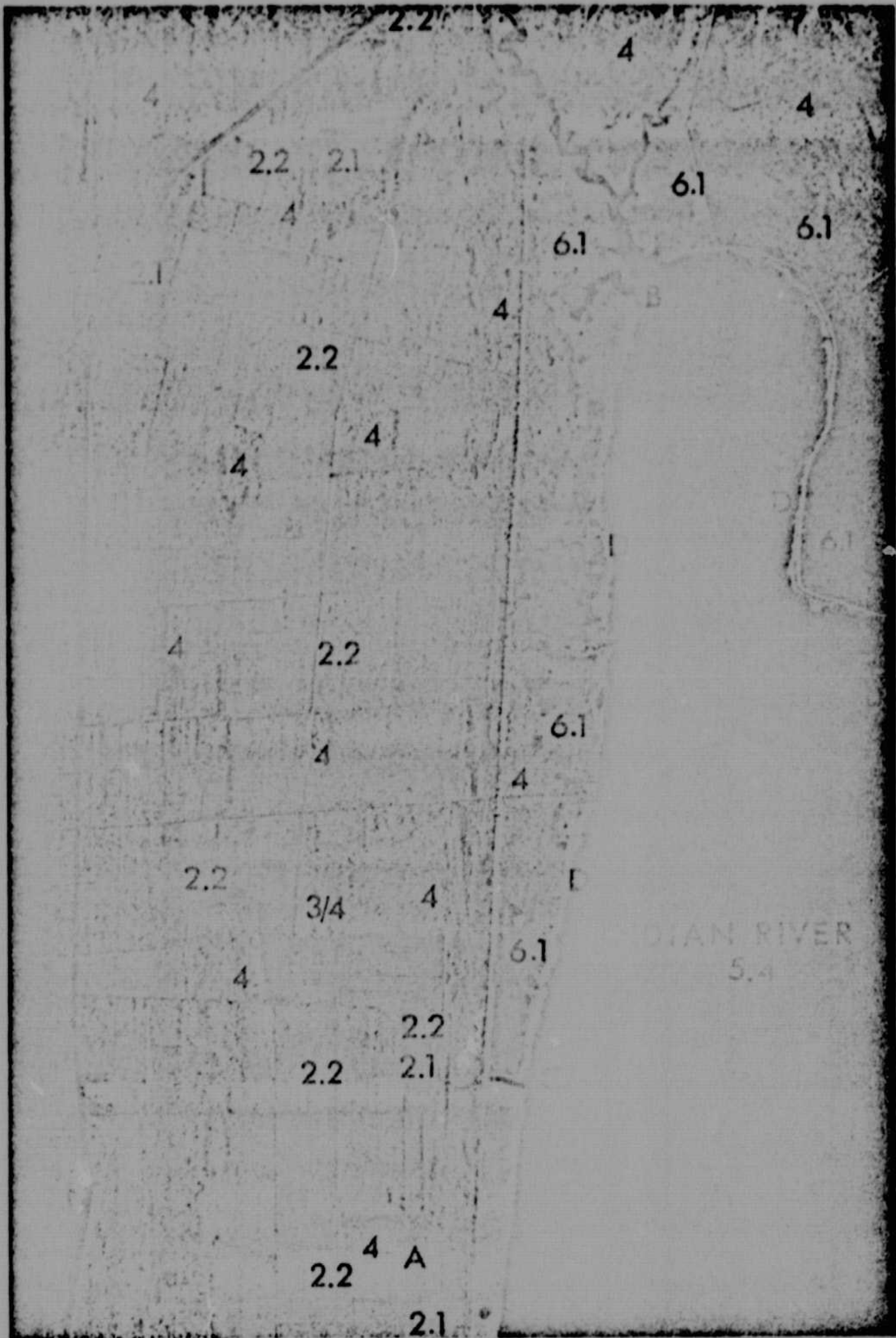
M. Determine how multiplexed SLAR imagery can be used for geologic mapping, particularly in the Appalachian Mountains. Special attention should be paid to the use of the SLAR imagery for structural, textural, and lithologic analysis. (The ERIM radar airplane crosses the Appalachian Mountains while in transit to most areas in the southeastern United States.)

N. Calibrate the multiplexed radar.

O. Add one or more wavelengths to the present multiplexed radar system.

ERIM

PLATE 1A
Radar Image
X-Band, Parallel Polarization



HEAD OF THE INDIAN RIVER, FLORIDA
Rural Land Use and Water Resources

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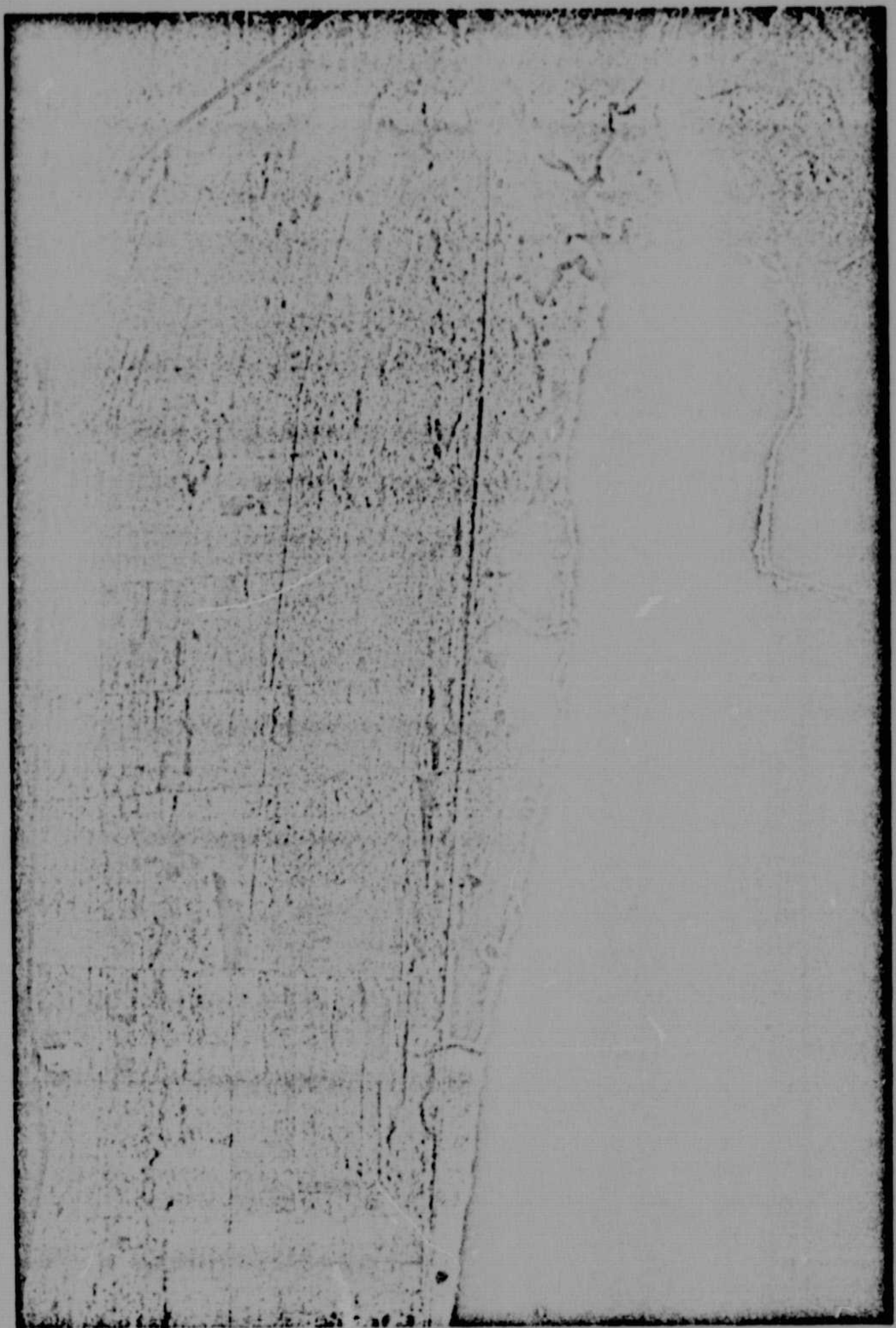
OF POOR QUALITY

ERIM

PLATE 1B
Radar Image
X-Band, Cross Polarization



HEAD OF THE INDIAN RIVER, FLORIDA
Rural Land Use and Water Resources

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ΣERIM

PLATE 1C
Radar Image
L-Band, Parallel Polarization

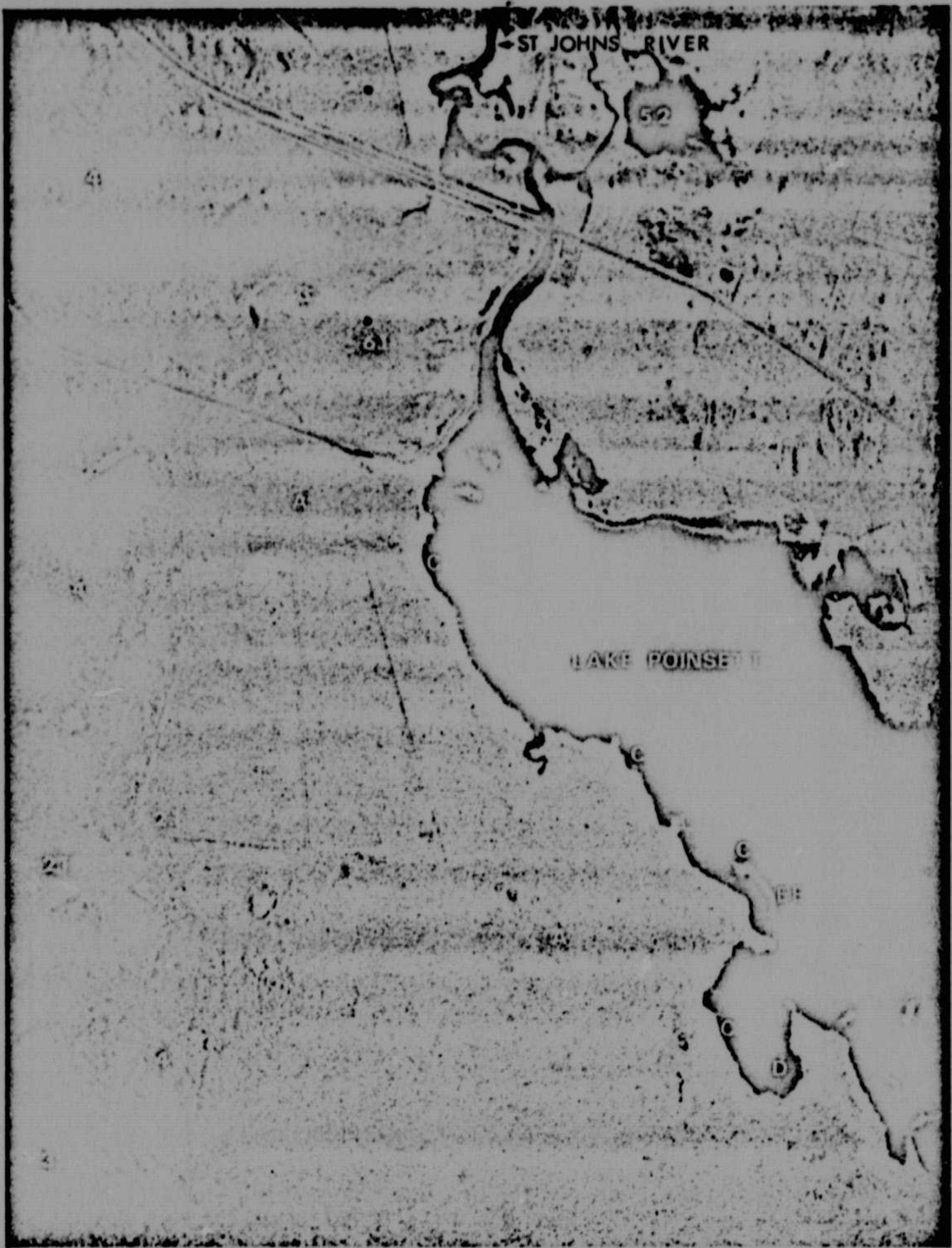
HEAD OF THE INDIAN RIVER, FLORIDA
Rural Land Use and Water Resources

ERIM

PLATE 1D
Radar Image
L-Band, Cross Polarization

HEAD OF THE INDIAN RIVER, FLORIDA
Rural Land Use and Water Resources

PLATE 5A
Radar Image
X-Band, Parallel Polarization

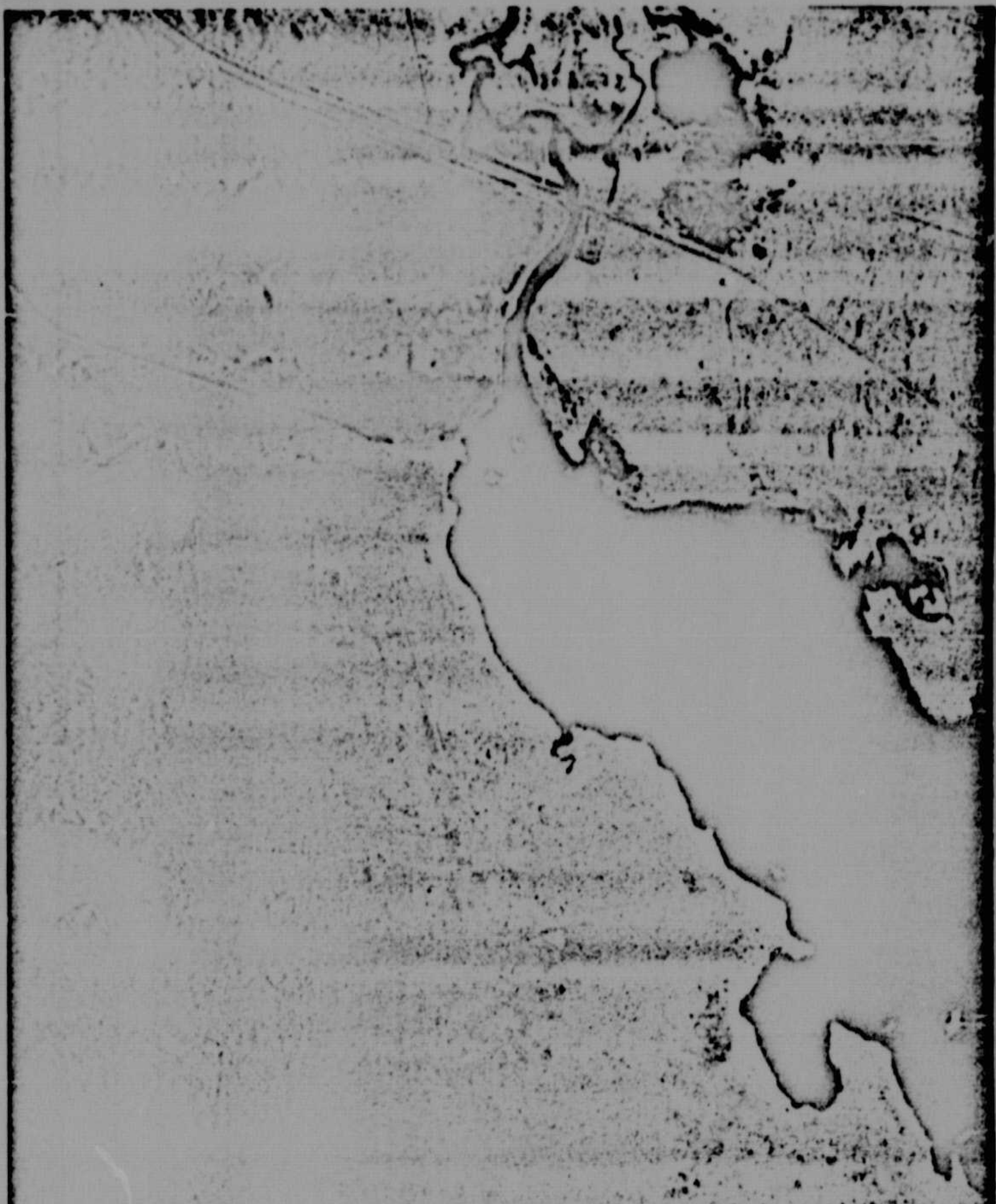


LAKE POINSETT REGION, ST. JOHNS RIVER, FLORIDA

Rural Land Use, Water Resources, and Drainage Patterns

ΣERIM

PLATE 5B
Radar Image
X-Band, Cross Polarization



LAKE POINSETT REGION, ST. JOHNS RIVER, FLORIDA
Rural Land Use, Water Resources, and Drainage Patterns

ΣERIM

PLATE 5C
Radar Image
L-Band, Parallel Polarization

LAKE POINSETT REGION, ST. JOHNS RIVER, FLORIDA
Rural Land Use, Water Resources, and Drainage Patterns

ΣERIM

PLATE 5D
Radar Image
L-Band, Cross Polarization

LAKE POINSETT REGION, ST. JOHNS RIVER, FLORIDA

Rural Land Use, Water Resources, and Drainage Patterns